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RCS Reduction of a Microstrip Patch Using Lumped Loads

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Abstract

In this report we consider the RCS of a single rectangular patch antenna in a recessed cavity. Using a previously developed finite element-boundary integral code, a study is performed on the patch's RCS as a function of frequency. To reduce the RCS of the patch at the resonant frequency, lumped (resistive) loads are placed at the edges of the patch. The effect of the lumped loads on the patch's RCS and gain are examined and it is observed that the RCS and gain are reduced as the load value decreases, whereas the antenna's bandwidth is increased. At resonance, the usual relation between RCS and gain is observed, but it is shown that this relation no longer holds at frequencies away from resonance.

Investigation's Scope

The purpose of this study is to (see figure 1):

- Study the RCS vs. Gain of the microstrip antenna by placing lumped resistive loads at the side aperture of the patch
- Determine the resonant frequency shift due to loading
- Assess bandwidth enhancement due to loading

This study was performed by using the University of Michigan program CAVITY3D (see Appendices). Other schemes for reducing the RCS of the patch and cavity edges using R-cards and dielectric coating are illustrated in figures 1 and 2, but these have not yet been considered.

Description of Investigation

To assess the effect of lumped loads on the RCS and Gain of the microstrip patch we considered a $5\text{cm} \times 3.4\text{cm}$ rectangular patch whose discretized form is shown in figure 3. This patch is loaded with four resistors placed roughly at the midpoint of each side as shown in figures 2 and 3. The thickness of the substrate/cavity was 0.17558cm and the relative dielectric constant was chosen to be $\epsilon_r = 2.17$. Also, for input impedance and gain computations the probe feed was placed at the bottom left corner of the patch as shown in figure 3.

For the above patch, the resonant frequency was found to be $f_0 = 1.94675\text{GHz}$ with the resistance of each load set at 1500Ω (essentially unloaded). At this frequency we proceeded to evaluate the Gain and RCS of the patch as the resistance was changed from 1500Ω down to zero Ohms (shorted). The normalized values of these quantities as a function of load resistance are plotted in figure 4 and it is clear from this data that the RCS reduction is twice (in dB) that of the Gain (the RCS in figure 4 was computed with no load at the feed). This is to be expected since the RCS at resonance is given by [1]

$$\sigma(\theta, \phi) = \frac{\lambda^2}{\pi} \{G'(\theta, \phi)\}^2$$

or

$$10 \log \sigma(\theta, \phi) = 2 \left\{ 10 \log [G'(\theta, \phi)] + 10 \log [\lambda / \sqrt{\pi}] \right\}$$

where $10 \log G'$ is the Gain in dB and includes any losses due to lumped or distributed loads. Let us assume that for a given load #1, the Gain is G'_1 and for another load #2, the Gain is G'_2 . The corresponding cross sections evaluated at the same frequency are then given by

$$\begin{aligned} 10 \log \sigma_1 &= 20 \log G'_1 + 10 \log \frac{\lambda}{\sqrt{\pi}} \\ 10 \log \sigma_2 &= 20 \log G'_2 + 10 \log \frac{\lambda}{\sqrt{\pi}} \end{aligned}$$

Subtracting these equations we obtain

$$\Delta \sigma_{dB} = 10(\log \sigma_1 - \log \sigma_2) = 2[10 \log G_1 - 10 \log G_2]$$

or

$$\Delta \sigma_{dB} = 2[G_{1dB} - G_{2dB}] = 2\Delta G_{dB}$$

which clearly shows that the dB RCS reduction is twice the dB gain reduction.

As expected, the input impedance becomes reactive with the addition of lumped loads and furthermore its real part is reduced in parallel with the lumped loads. Thus the patch's resonant frequency changes with the value of the applied load. The specific values are illustrated in figure 5 and the reason for the input resistance's reduction is that the lumped loads placed between the patch edges and the ground are in a parallel arrangement with the impedance originally observed at the feed. However, we note that the radiation patterns are essentially unaffected by the placement of the loads (see figures 6(a) and 6(b)). More specifically, the radiation pattern corresponding to the 300Ω loads is completely identical to that associated with the unloaded patch. We will thus choose to retune the patch with this load placed at its four side apertures (in actuality only the loads at two of the apertures are of significance since the field at the midpoint of the other two vanishes when the patch is at resonance).

The resonant frequency (the frequency at which the input impedance is real) with the feed at the lower left corner ($x = 1.25$, $y = 0.85$ position) of the patch and with the 300Ω loads at the patch edges was found to be $f_0 = 1.97\text{GHz}$. As given in figure 7 the input resistance at this frequency is approximately 103.5Ω , and as shown in this figure, the input impedance

changes rather substantially as the feed position changes. Interestingly, when the feed is at $(x = 2.5\text{cm}, y = 1.7\text{cm})$, the input impedance is again real and equal to approximately 49Ω , a value which matches the characteristic impedance of common coaxial cables. From fig. 7, it is also observed that the gain is essentially unaffected by the feed's position implying that the radiation pattern is also unaffected.

With the feed at $(x = 2.5\text{cm}, y = 1.7\text{cm})$ and the 300Ω loads at the patch edges, we next examined the patch VSWR and bandwidth. The results are given in figures 8 and 9, and the assumed source/line impedance was that at $f_0 = 1.97\text{GHz}$ (i.e., $Z_0 \simeq 49\Omega$). It is seen that the patch bandwidth is increased substantially from fig. 8. Specifically, the bandwidth of the 300Ω loaded patch is approximately 0.13 (normalized frequency range within which $\text{VSWR} < 3$) whereas that of the unloaded patch is only 0.02 (more than six times smaller). The RCS of the 300Ω loaded patch in the vicinity of the resonant frequency is shown in figure 10 with or without a load of 49Ω across the patch at the feed point. As expected, the RCS is maximum at the resonant frequency and then drops rather rapidly away from this frequency. When the 49Ω load is placed at the feed to simulate the presence of the coax line, a 7dB reduction is observed at the resonant frequency. A more extensive frequency sweep of RCS for different loading configurations can be seen in figure 11. Here we are comparing an unloaded patch to one loaded with four 300Ω resistors and to another loaded with four 300Ω along with the 49Ω at the feed (coax line simulation). Again we observe the expected RCS reduction at the points of resonance.

Conclusions

One can readily conclude from the above study that the RCS of a patch at resonance can be substantially reduced by placing lumped loads at its side edges. The reduction in RCS achieved in this manner is about twice (in dB) the corresponding reduction in gain. It was also noted that the resonant frequency is a function of the load's value and thus the patch must be retuned for each load. Alternatively, it was shown that the feed location can be moved to again achieve resonance or simply to find an input resistance that matches that of the feeding line.

Future Study

During the next month we shall investigate the RCS and gain of the patch when a dielectric coating is placed on its upper surface. Also the effect of a uniform R-card across the aperture will be studied. For the first case, a modification of the program is required.

References

- [1] David R. Jackson, "The RCS of a Rectangular Microstrip Patch in a Substrate-Superstrate Geometry," IEEE Trans. Antennas and Propagat., AP-38, pp. 2-8, Jan. 1990.

Appendices

Gain Calculations from Program Output Parameters

By definition,

$$\text{Gain} = G'(\theta, \phi) = \lim_{r \rightarrow \infty} \frac{4\pi r^2 \frac{1}{2Z_0} |E^r(\theta, \phi)|^2}{P_{\text{in}}}$$

where E^r is the radiated field as a function of the spherical angles θ and ϕ , Z_0 is the free space intrinsic impedance, r is the distance to the observation point and P_{in} denotes the input power. For a probe feed, we have that

$$P_{\text{in}} = \frac{1}{2} V I^* = \frac{1}{2} R_{\text{in}} |I|^2 = \frac{1}{2} R_{\text{in}},$$

since $I = 1 \text{ Amp.}$, in which $R_{\text{in}} = \text{Re}\{Z_{\text{in}}\}$ is the antenna input resistance. It then follows that

$$G'(\theta, \phi) = \frac{4\pi \left(\frac{r}{\lambda_{\text{cm}}}\right)^2 |E^r(\theta, \phi)|^2}{Z_0 R_{\text{in}}} \lambda_{\text{cm}}^2$$

in which λ_{cm} denotes the wavelength in centimeters. The dB value of this expression is computed as

$$G'_{\text{dB}}(\theta, \phi) = 10 \log_{10} \left[4\pi \left(\frac{r}{\lambda_{\text{cm}}}\right)^2 |E^r(\theta, \phi)|^2 \right] + 10 \log_{10} \left[\frac{\lambda_{\text{cm}}^2}{Z_0 R_{\text{in}}} \right]$$

The first term in this expression is that computed by the program CAVITY3D and is referred to in that program as the radiated power. The second term must therefore be added externally from the computed value of R_{in} also given by the program.

RCS Calculation from Program Output Parameters

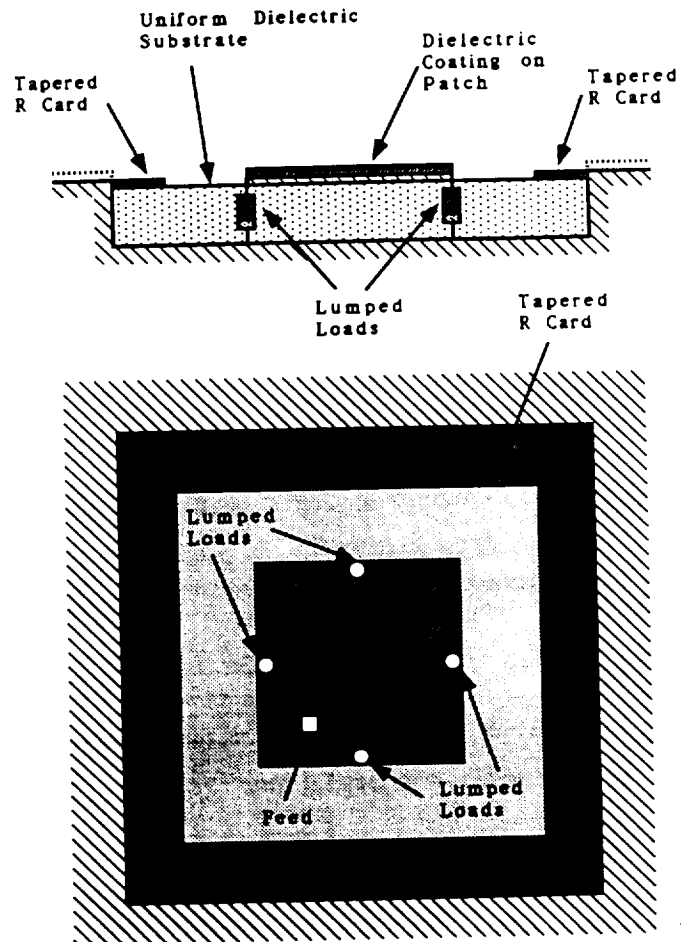
The RCS computed by the program CAVITY3D is given in dB above a square wavelength. To obtain the RCS in square meters the following formula must be applied externally:

$$\sigma_{\text{dBSM}} = \sigma_{\text{dBSW}} + 20 \log_{10}(\lambda_{\text{m}})$$

where λ_{m} is the wavelength in meters.

RCS Reduction Studies

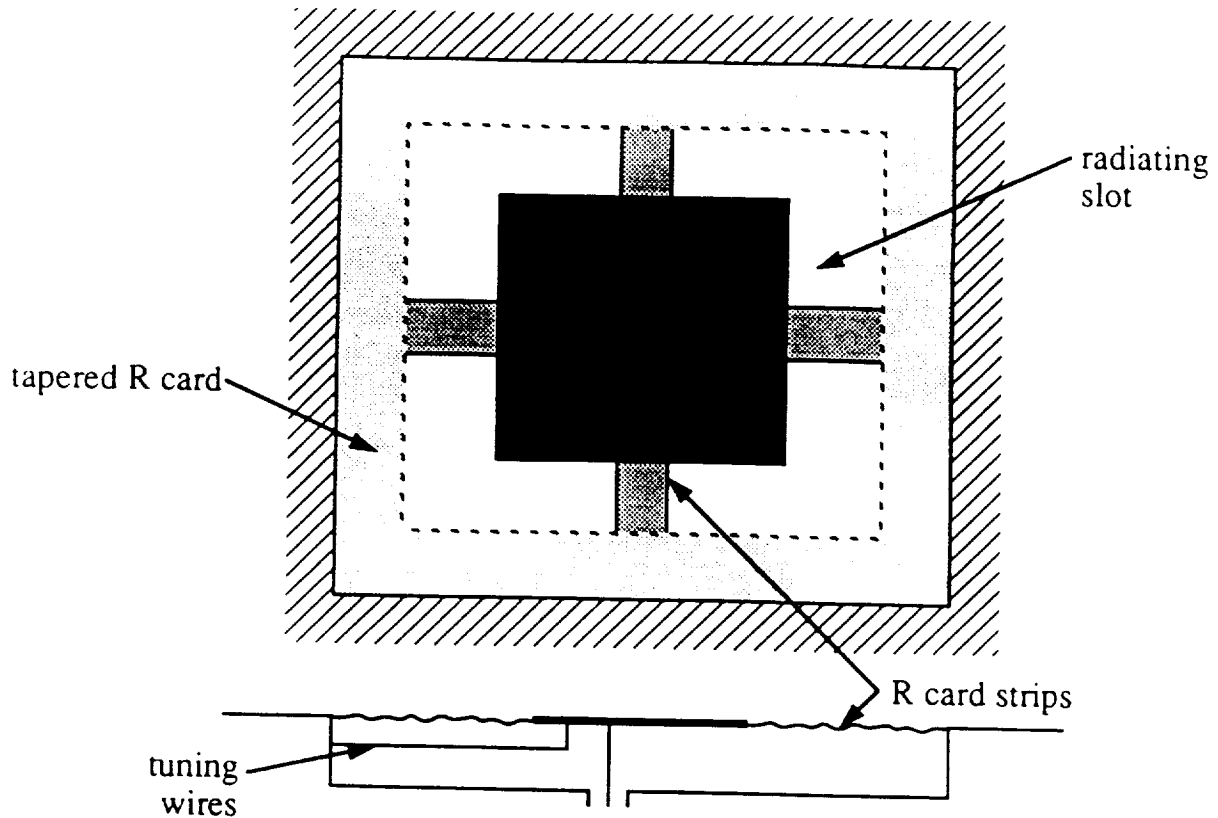
- Resistive cards
- Lumped loads
- Shape
- Feed mechanism



- Study RCS vs gain characteristics for various load treatments
- Study resonant frequency shift due to loading
- Study bandwidth enhancement as a function of loading

Figure 1

Other RCS reduction approaches for simple elements



- Tapered R Card reduces RCS of terminations without effecting antenna parameters.
- R Card strips act as lumped loads in reducing the RCS. They reduce RCS and Gain, but RCS is usually reduced much more.
- Patch must be retuned after loading.
- Radiation pattern is generally unaffected.
- Surface wave effects are suppressed because of cavity enclosure.

Goal: Given certain criteria with respect to Gain, bandwidth, and RCS at the design frequency, what should be the loading, feed mechanism and structural characteristics of the patch antenna?

Figure 2

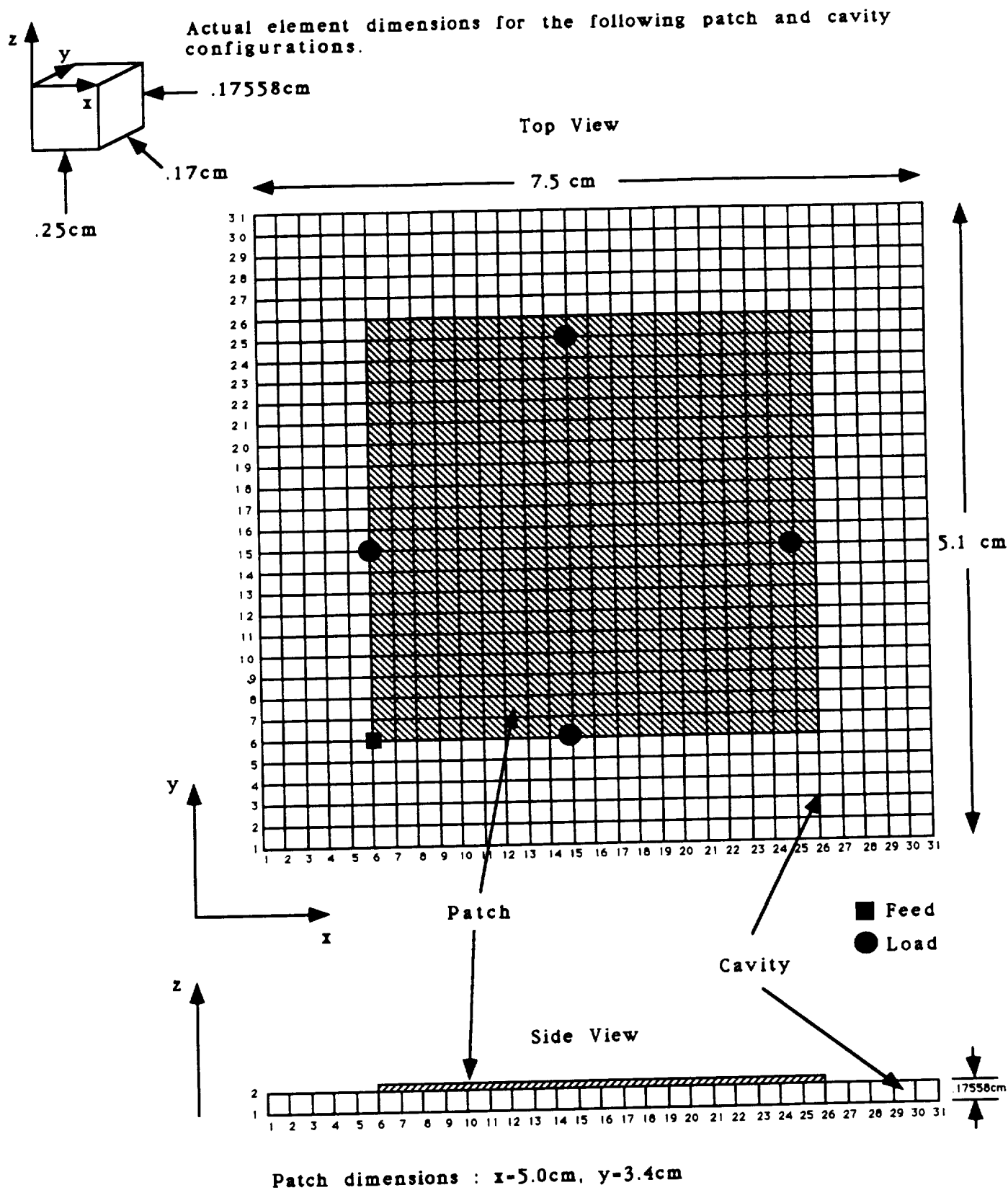


Figure 3

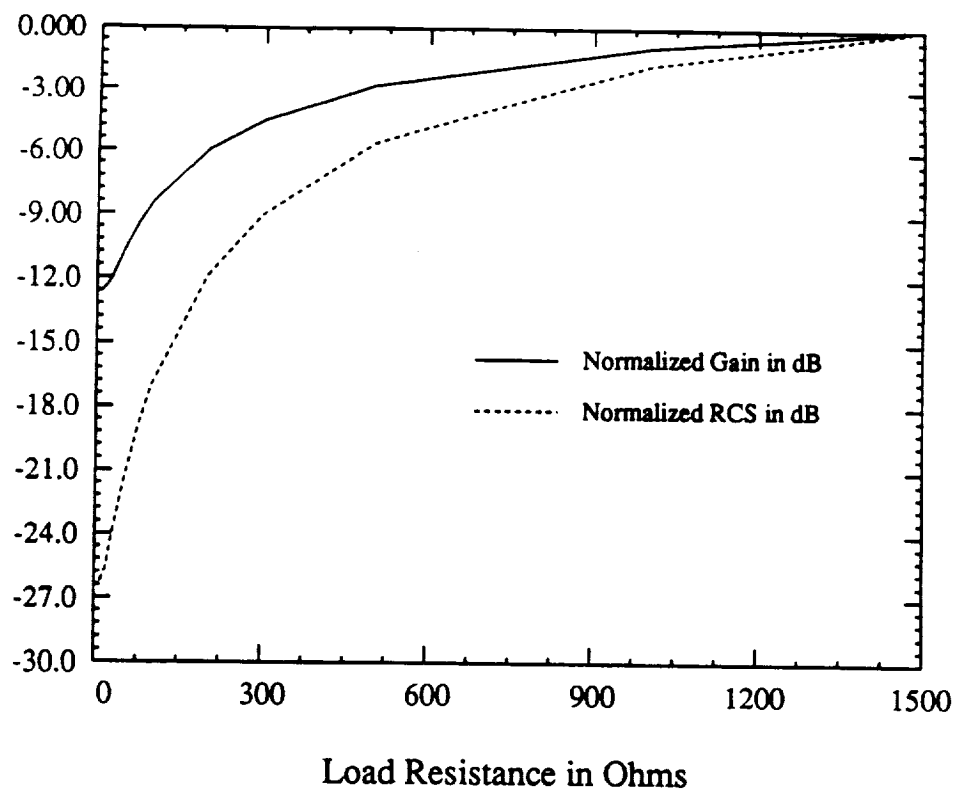


Figure 4

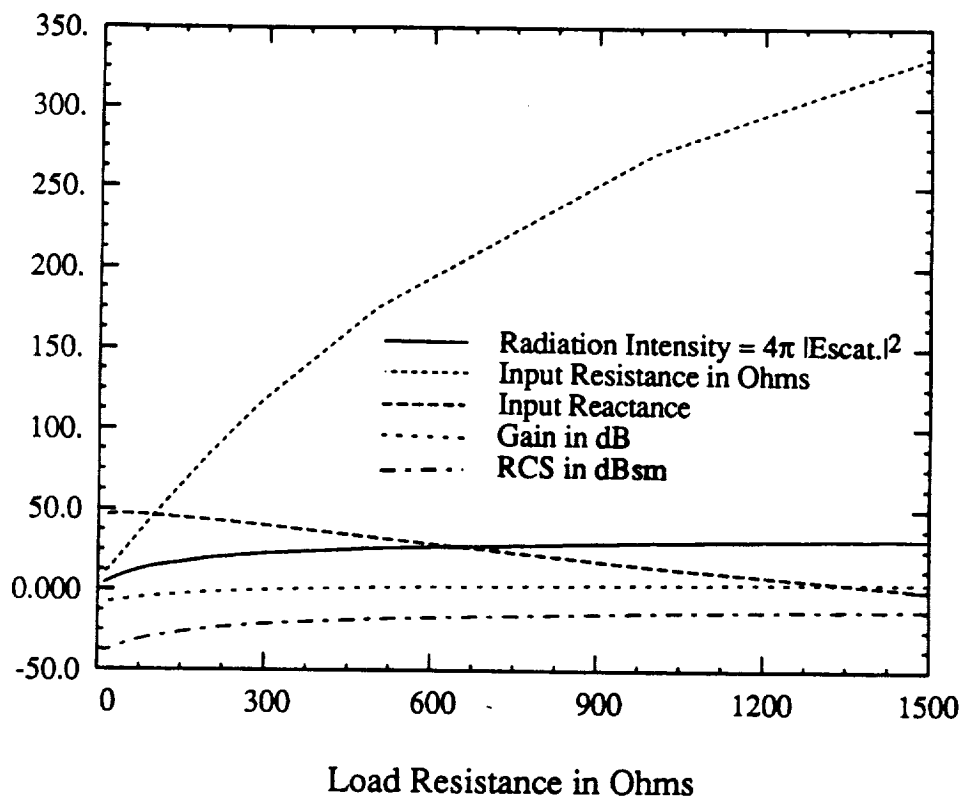


Figure 5

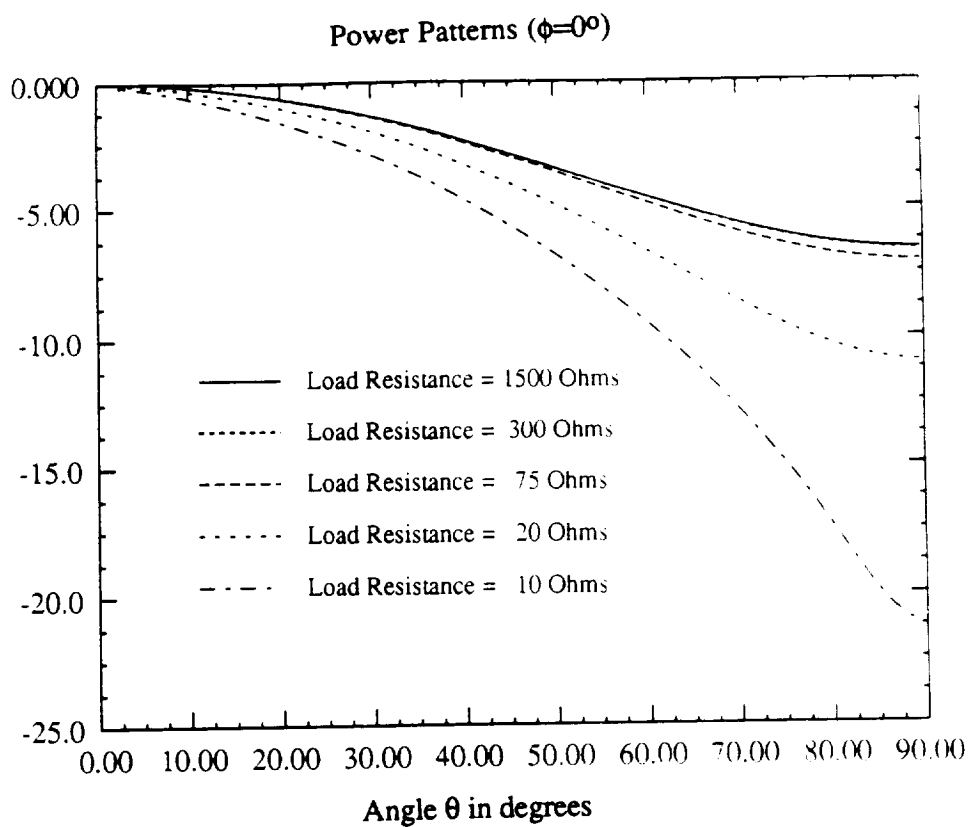


Figure 6(a)

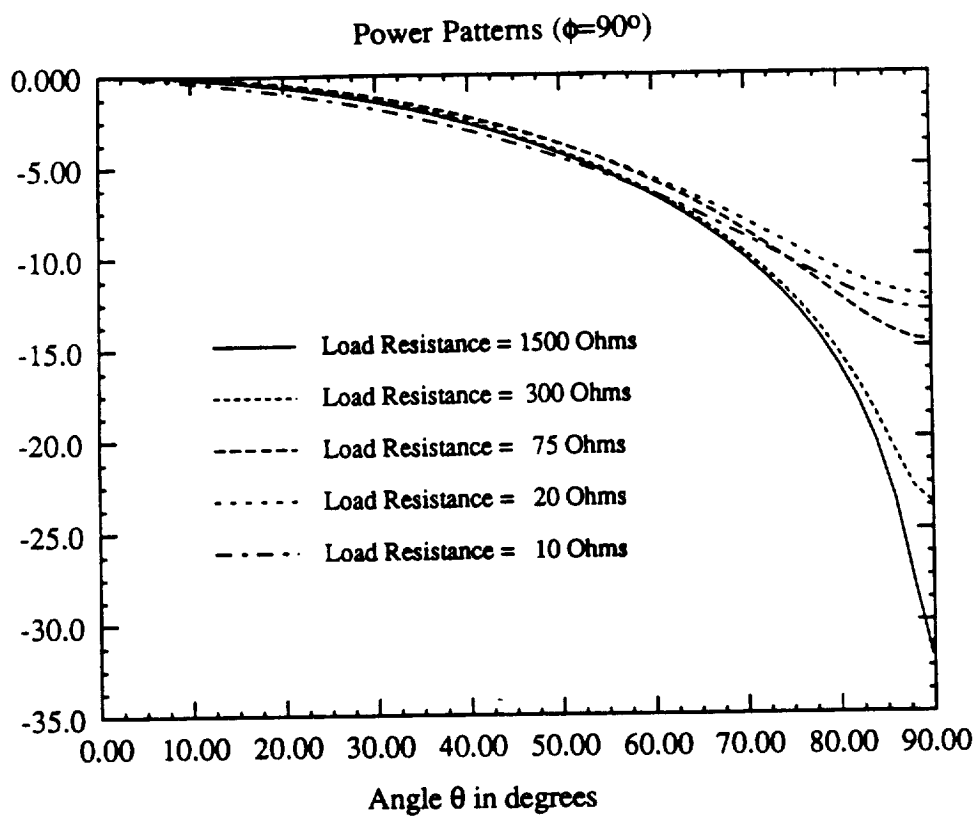


Figure 6(b)

Radiation Properties of Patch as Feed is Moved

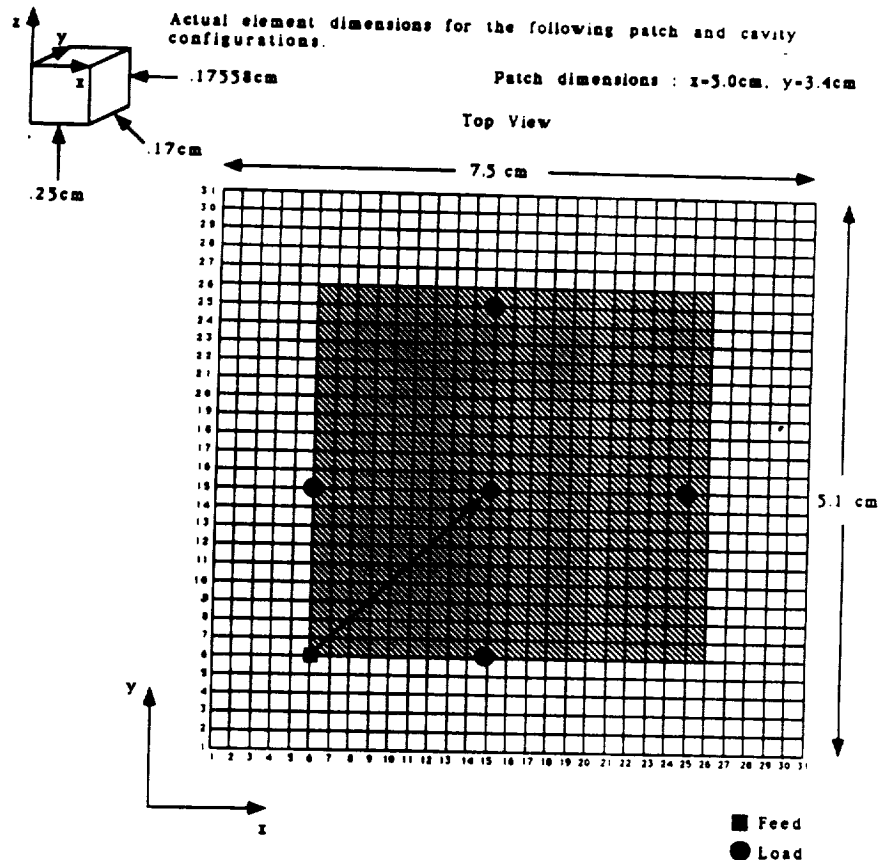
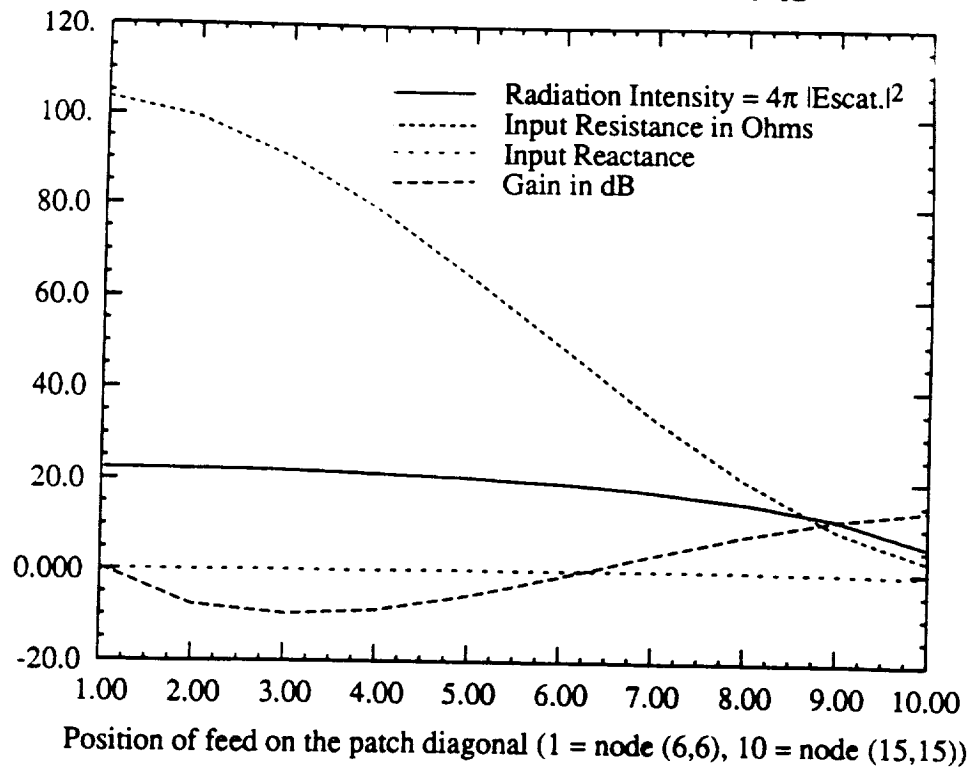


Figure 7. The arrow on the patch above indicates the motion of the feed with initial and final positions at nodes (6,6)-and (15,15) respectively. The frequency is 1.97GHz which happens to be the resonant frequency for four 300Ω loads and the feed at node (6,6). With the feed at node (11,11) it is interesting to note that the input impedance becomes approximately 50Ω (ie. 48.92-j1.13 Ω).

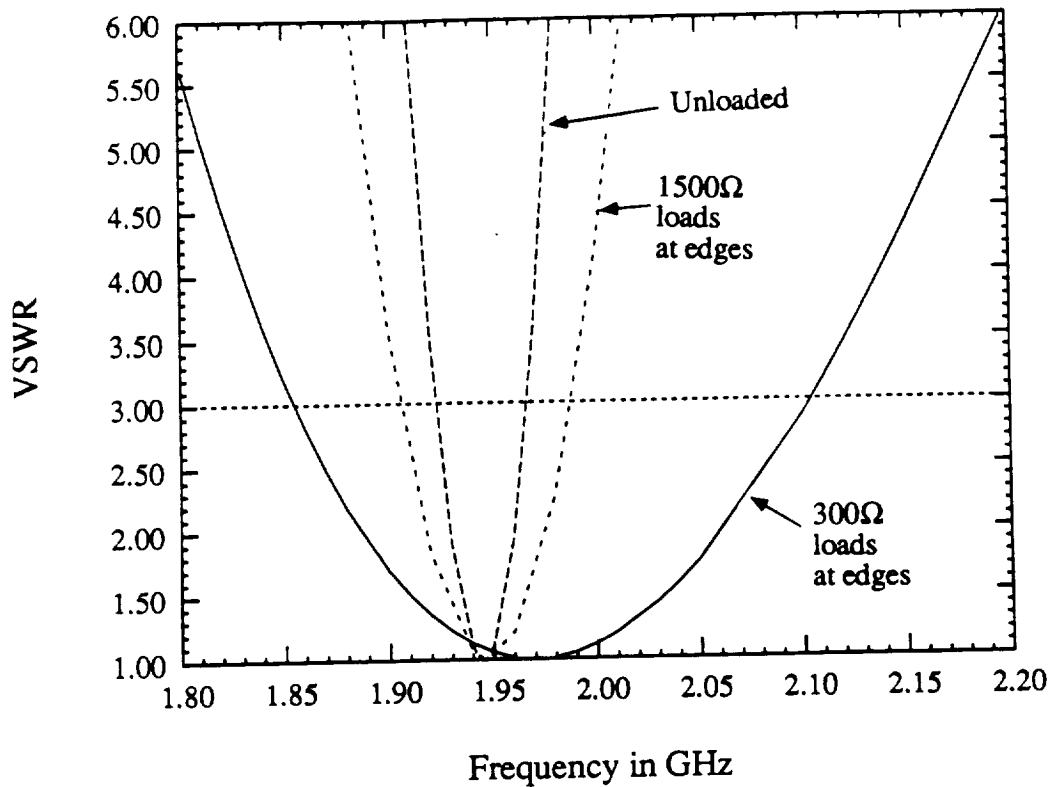


Figure 8. VSWR of loaded and unloaded patch vs frequency

Computation of VSWR :

$$\text{VSWR} = (1+|\Gamma|)/(1-|\Gamma|) \quad \text{where } \Gamma = (Z_{in}-Z_{inr})/(Z_{in}+Z_{inr})$$

$Z_{inr} = 48.92-j1.13 \, \Omega$ is the input impedance at the resonant frequency (1.97GHz) for four 300Ω loads and feed at node position (11,11). Note that at this frequency VSWR=1.

Z_{in} = input impedance for the same configuration as above, with the exception that the frequency varies.

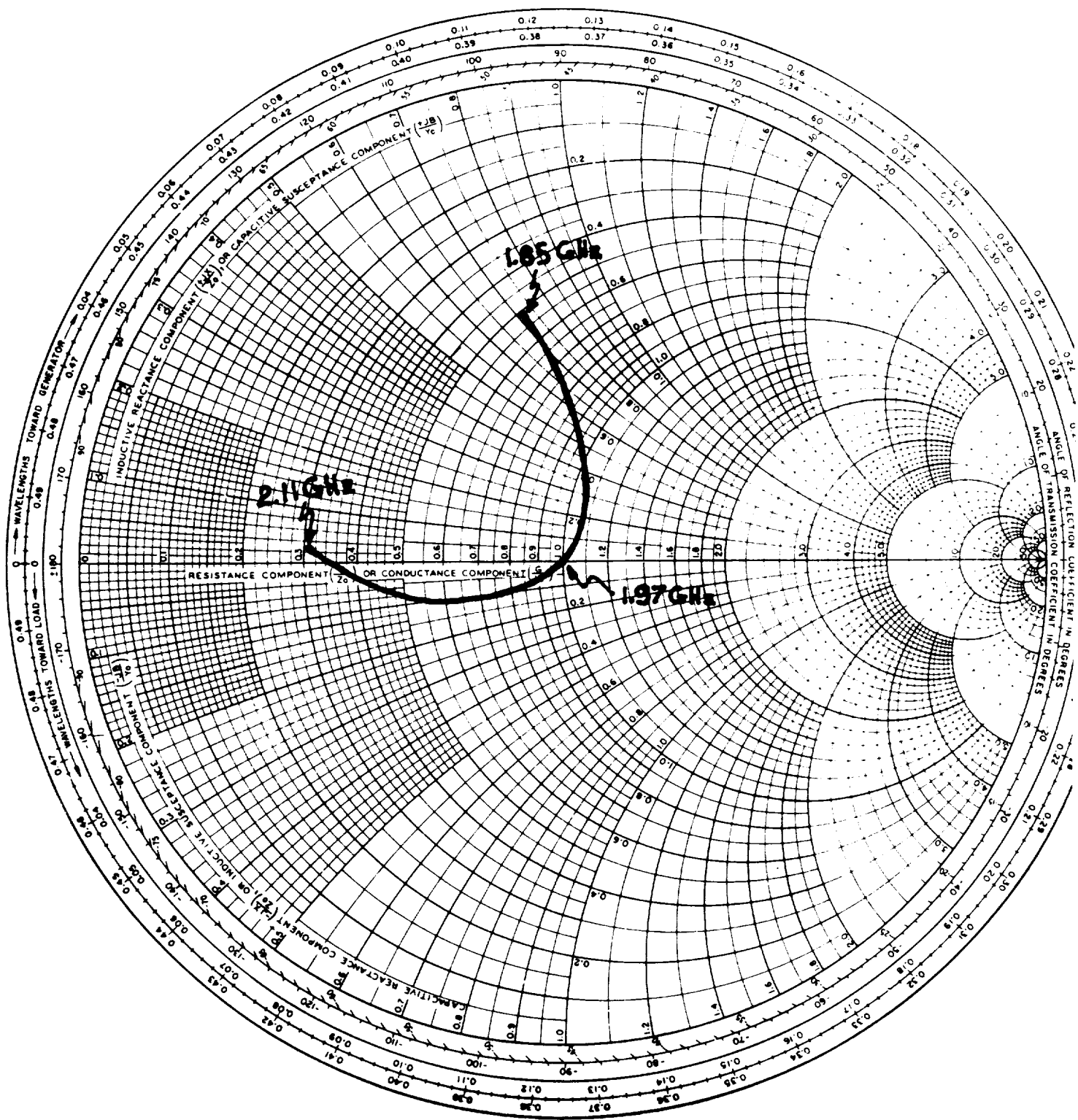


Figure 9. Γ (as defined in figure 8) vs frequency on a smith chart. Note that the endpoints of this graph correspond to VSWR=3.

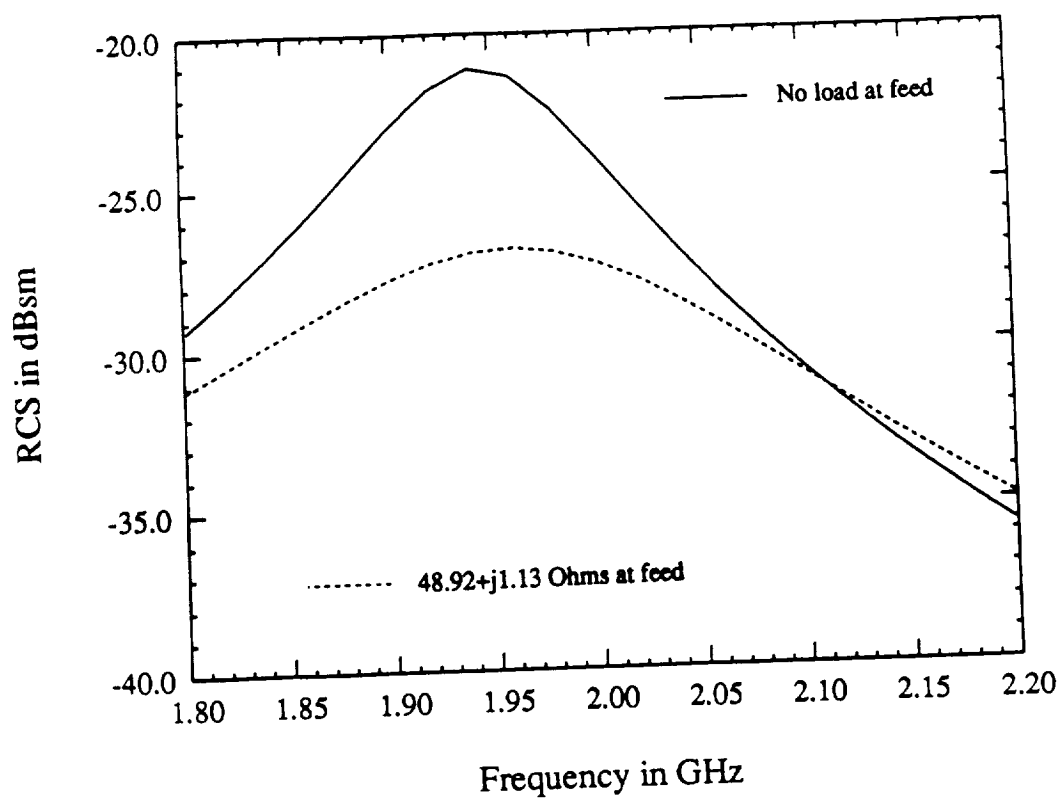


Figure 10. RCS as a function of frequency

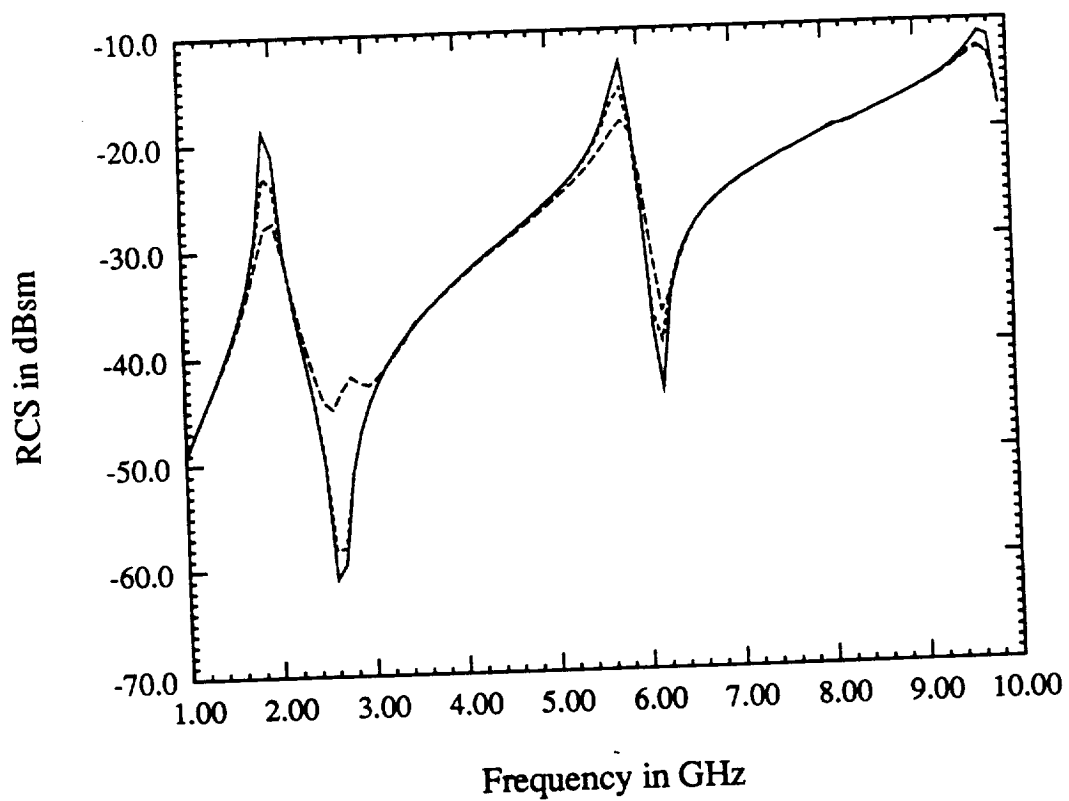


Figure 11. RCS as a function of frequency

Typical input file

7.5 5.1 .17558	cavity size in cm (x,y,z)
31 31 2	number of nodes (x,y,z)
1	- uniform dielectric
(2.17,0) (1.,0.)	substrate dielectric - ϵ_r μ_r
1.97 1.97 1	frequency min, max, increment
2	- radiated intensity calculation
0 0 1	theta min, max, increment
0 0 1	phi min, max, increment
.01 800	tolerance, number of iterations
2	- monitor cnvergence 1=yes 2=no
1	number of patch
6 6	lower left corner of patch node(x,y)
20 20	number of elements on patch (x,y)
1	layer in which patch resides
2	- patch display 1=yes 2=no
0	number of short circuit pins
1	number of feeds
11 11	feed position node(x,y)
1 0	amplitude and phase of current source
1	layer in which feed is embedded
4	number of loads
15 6	node(x,y) load 1 position
(300.,0.)	value of load 1 (complex) in Ω
1	layer in which load 1 is embedded
25 15	node(x,y) load 2 position
(300.,0.)	value of load 2 (complex) in Ω
1	layer in which load 2 is embedded
15 25	node(x,y) load 3 position
(300.,0.)	value of load 3 (complex) in Ω
1	layer in which load 3 is embedded
6 15	node(x,y) load 4 position
(300.,0.)	value of load 4 (complex) in Ω
1	layer in which load 4 is embedded
2	- resistive card 1=yes 2=no

Figure 12

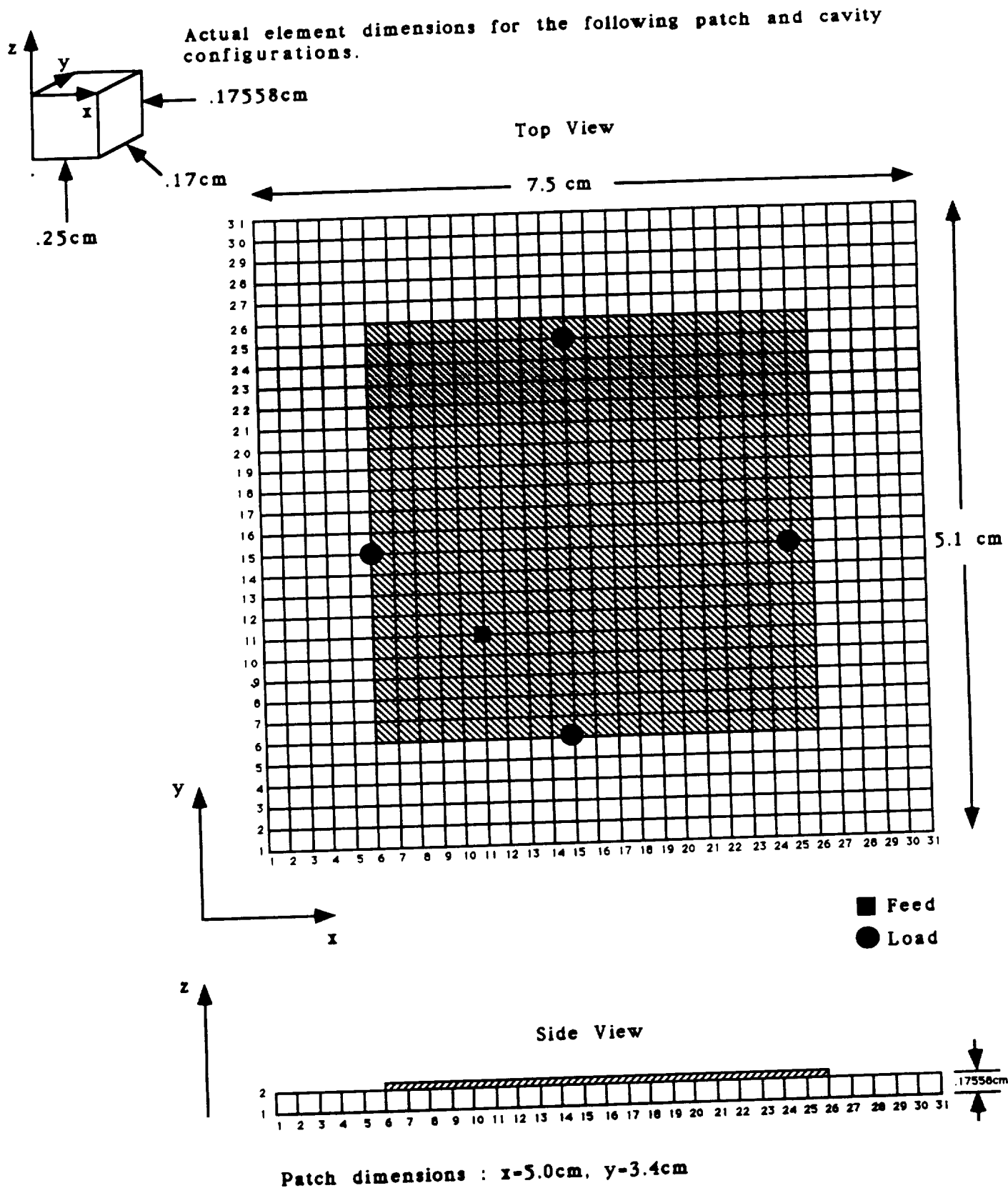


Figure 13. This is the exact patch-cavity configuration resulting from the input file given in figure 12.

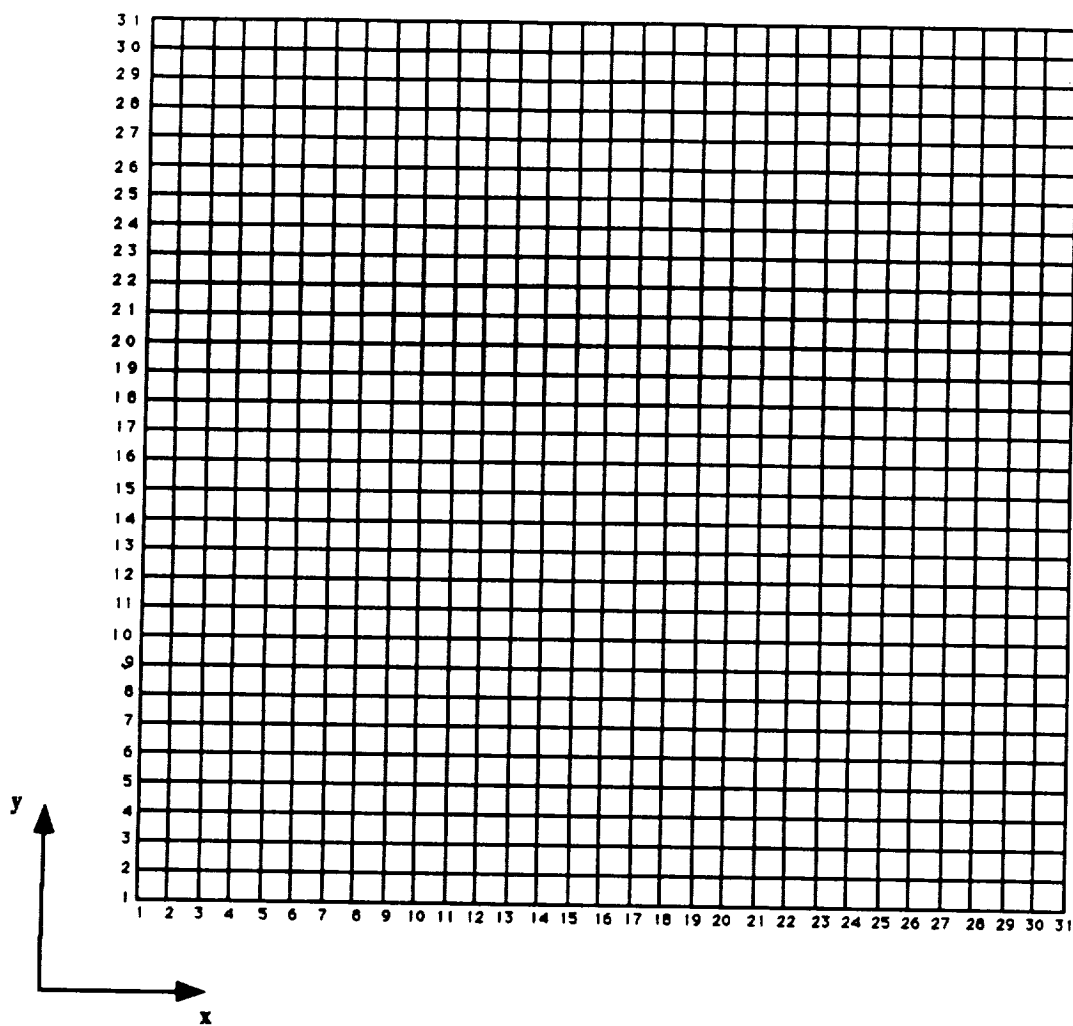


Figure 14. Extra grid for future designs.